

## **Indexing astronomical database tables using HTM and HEALPix**

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**Abstract.** In various astronomical projects it is crucial to have coordinates indexed tables. All sky optical and IR catalogues have up to 1 billion objects that will increase with forthcoming projects. Also partial sky surveys at various wavelengths can collect information (not just source lists) which can be saved in coordinate ordered tables. Selecting a sub-set of these entries or cross-matching them could be un-feasible if no indexing is performed. Sky tessellation with various mapping functions have been proposed. It is a matter of fact that the astronomical community is accepting the HTM and HEALPix schema as the default for object catalogues and for maps visualization and analysis, respectively. Within the MCS library project, we have now made available as MySQL-callable functions various HTM and HEALPix facilities. This is made possible thanks to the capability offered by MySQL 5.1 to add external plug-ins. The DIF (Dynamic Indexing Facilities) package distributed within the MCS library, creates and manages a combination of Views, Triggers, DB-engine and plug-ins allowing the user to deal with database tables indexed using one or both these pixelisation schema in a completely transparent way.

### **1. Introduction**

Spatial indexes has always been an important issue for multi dimensional data sets in relational databases (DBs), in particular for those dealing with spherical coordinates, e.g. latitude/longitude for Earth locations or RA/Dec for celestial objects. Some DB servers offer built-in capabilities to create indexes on these (coordinate) columns which consequently speed up the execution of queries involving them. However 1. the use of these facilities could be not easy, 2. they typically use a syntax quite different from the astronomical one, 3. their performance is inadequate for the astronomical use.

Within the MCS library project (Calderone & Nicastro 2007; Nicastro & Calderone 2006, 2007; [ross.iasfbo.inaf.it/MCS/](http://ross.iasfbo.inaf.it/MCS/)) we have implemented the DIF package, a tool which performs and manages in a fully automatic way the sky pixelisation with both the HTM (Kunszt et al. 2001) and HEALPix (Górski et al. 2005) schema. Using a simple tool, any DB table with sky coordinates columns can be easily indexed. This is achieved by using the facilities offered by the MySQL DB server (which is the only server MCS supports at the moment), i.e. triggers, views and plugins. Having a table with sky coordinates, the user can make it fully indexed in order to perform quick queries on rectangular and

circular regions (cone) or to create an HEALPix map file. An SQL query to select objects in a cone will look like this: `SELECT * FROM MyCatalogue WHERE EntriesInCone(20, 30, 5)`, where (20,30) are the coordinates of the center in degrees and 5 is the radius in arcmin. The important thing to note is that the DB manager needs to supply only a few parameters in the configuration phase, whereas the generic user does not need to know anything about the sky pixelisation either for `SELECT` or `INSERT` or `UPDATE` queries. It also demonstrates that there is no need to extend standard SQL for astronomical queries (see ADQL), at least if MySQL is used as DB server.

## 2. Indexing on a sphere

In terms of DB table indexing, mapping a sphere with a pixel scheme means transforming a 2-d into a 1-d space, consequently a standard B-tree index can be created on the column with the pixel IDs. On a large astronomical table, depending on the “depth” of the pixelisation, this could lead to a gain of a 4–5 orders of magnitude in search efficiency. The HTM and HEALPix schema are widely used in Astronomy and are now well mature to be considered as candidates for indexing tables containing astronomical data. They are both open source and distributed as C++ libraries. HTM uses triangular pixels which can recursively be subdivided into four pixels. The base pixels are 8, 4 for each hemisphere. These “trixels” are not equal-area but the indexing algorithm is very efficient for selecting point sources in catalogues. HEALPix uses equal-area pseudo-square pixels, particularly suitable for the analysis of large-scale spatial structures. The base pixels are 12. Using a 64 bit long integer to store the index IDs leads to a limit for the pixels size of about 7.7 and 0.44 milli-arcsec on a side for HTM and HEALPix, respectively. Being able to quickly retrieve the list of objects in a given sky region is crucial in several projects. For example hunting for transient sources like GRBs requires fast catalogues lookup so to quickly cross match known sources with the detected objects. The IR/optical robotic telescope REM (Nicastro & Calderone 2006) uses HTM indexed catalogues to get the list of objects in  $10' \times 10'$  regions. In this case accessing one billion objects catalogues like the GSC2.3 takes some 10 msec. Having a fully automatic HTM and HEALPix indexing would be crucial for the management of the DBs of future large missions like Gaia. Also the Virtual Observatory project would greatly benefit from adopting a common indexing scheme for all the various types of archive it can manage. The relevant parameters for the two pixelisations are:

	<b>HTM</b>	<b>HEALPix</b>
$N_{\text{pix}}^{\dagger}$ :	$8 \times 4^d$	$12 \times N_{\text{side}}^2$ (where $N_{\text{side}} = 2^k$ )
ID range:	$[N_{\text{pix}}, 2 \times N_{\text{pix}} - 1]$	$[0, N_{\text{pix}} - 1]$
Max $N_{\text{pix}}$ :	$\simeq 9.0 \times 10^{15}$	$\simeq 3.5 \times 10^{18}$
Max res. ("':	$7.7 \times 10^{-3}$	$3.9 \times 10^{-4}$ ( $\Omega_{\text{pix}} = \pi / (3 \times N_{\text{side}}^2)$ )

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<sup>d</sup> $d$  (depth): [0, 25];  $k$  (order  $\Leftrightarrow$  resolution parameter): [0, 29]

As mentioned the maximum resolution is related to the usage of 64 bit integers and it is intrinsic to the HTM and HEALPix C++ libraries.

### 3. The MCS DIF package

MCS is a set of C++ high level classes aimed at implementing an application server, that is an application providing a service over the network. MCS provides classes to interact with, manage and extend a MySQL DB server. The included MyRO package allows a per row management of DB grants whereas the DIF package allows the automatic management of sky pixelisation with the HTM and HEALPix schema. See the MCS web site for more information.

To enable DIF, when installing MCS it is enough to give to the configure script the two options `--enable-dif --with-mysql-source=PATH` where PATH is the path to the MySQL source directory. The HTM and HEALPix C++ libraries are included in the DIF package. A DB named DIF will be created containing an auxiliary table `tbl` and a *virtual* table `dif` which is dynamically managed by the DIF DB engine. Now let's assume one has a DB MyDB with a table `MyCat` containing the two coordinates column `RAcs` and `DECcs` representing the centi-arcsec converted J2000 equatorial coordinates (this requires 4 bytes instead of the 8 necessary for a double value). To make the table manageable using both the HTM and HEALPix pixelisation schema it is enough to give the command:

```
dif --index-both MyDB MyCat 6 0 8 "RAcs/3.6E5" "DECcs/3.6E5"
```

where `dif` is the name of the script used to perform administrative tasks related to DIF-handled tables, 6 is the HTM depth and 8 is the HEALPix order whereas the 0 (1) selects the RING (NESTED) scheme. The last two parameters are the SQL expressions which convert to degrees the coordinate values contained in the table fields `RAcs` and `DECcs`. If the coordinates were already degrees, then it would have been enough to give their names, e.g. `dif ... RA DEC`. The MySQL root password is needed. In a future release we'll add the possibility to perform simple cross matching between (DIF managed) catalogues. Having an HTM indexed catalogue, the query string to obtain the list of objects in a circular region centred on  $\alpha = 60^\circ$  and  $\delta = 30^\circ$  with radius  $40'$  will be:

```
SELECT * FROM MyCat_htm WHERE DIF_HTMCircle(60,30,40);
```

note the table name `_htm` suffix which is needed to actually access the view handled by DIF. For a rectangle with the same centre and sides  $50'$  along the  $\alpha$  axis and  $20'$  along the  $\delta$  axis:

```
SELECT * FROM MyCat_htm WHERE DIF_HTMRect(60,30,50,20);
```

giving only three parameters would imply a square selection. Having chosen to use both HTM and HEALPix indexing, one could request all the HEALPix IDs of the objects in a  $50'$  square by using an HTM function:

```
SELECT healpixID FROM MyCat_htm WHERE DIF_HTMRect(60,30,50);
```

To simply get the IDs of the pixels falling into a circular/rectangular region one can simply `SELECT id FROM DIF.dif WHERE ...`, i.e. no particular DIF managed table is required. To obtain the order 10 IDs in RING scheme one can calculate them on the fly:

```
SELECT DIF_HEALPLookup(0,10,RAcs/3.6E5,DECcs/3.6E5)
```

```
FROM MyCat_htm WHERE DIF_HTMCircle(60,30,20);
```

Giving 1 instead of 0 would give NESTED scheme IDs. Having RA and DEC in degrees one would simply type `(0,10,RA,DEC)`. If one has just the HEALPix IDs then entries on a circular region can be selected like in:

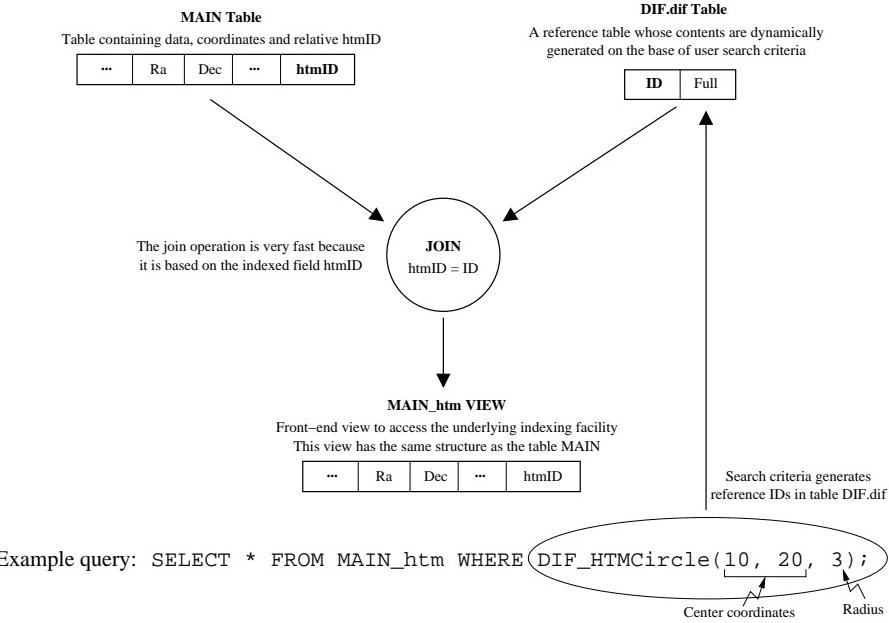


Figure 1. This diagram summarises the way DIF works for the HTM indexing case. The extra column `htmID` is added to the original table `MAIN` and a view is created which performs a join with the dynamical table `DIF.dif`. Triggers to automatically manage `INSERT` and `UPDATE` queries are also created. We recall that MCS allows users to interact with such MySQL server using programs written in any language.

```
SELECT * FROM MyCat_healp WHERE DIF_HEALPCircle(60,30,40);
note the table name _healp suffix. Rectangular selections for only-HEALPix
indexed tables will be available in the future. The current list of functions is:
DIF_HTMCircle, DIF_HTMRect, DIF_HTMRectV, DIF_HEALPCircle,
DIF_HTMLookup, DIF_HEALPLookup, DIF_Sphedist.
```

`DIF_HTMRectV` accepts the four corners of a rectangle which can then have any orientation in the sky. `DIF_Sphedist` calculates the angular distance of two points on the sphere by using the haversines formula. A first version of IDL user contributed library and demo programs aimed at producing HEALPix maps from the output of SQL queries is available at the MCS web site.

## References

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